Comparision of the Masers at the Geodetic Observatory Wettzell

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Abstract The Geodetic Observatory Wettzell operates three hydrogen masers as a part of the Wettzell atomic clock ensemble. The long term evolution of the masers is continuously measured. For the investigation of the short term behavior, a 14-day measurement campaign was carried out. The results presented in this paper are in good accordance with previous measurements and the specifications of the maser. With regard to improvements in the time and frequency department of the observatory, the results also show that steering should have no influence on the short term stability of the maser.

Keywords Time and frequency, hydrogen maser, Allan deviation

1 Introduction

The Geodetic Observatory Wettzell features a time laboratory with five commercial Caesium clocks and three hydrogen masers. All clocks take part in the calculation of UTC and are reported regularly to the BIPM. The UTC at the observatory *UTC(IFAG)* is realized with a commercial caesium clock.

The maser ensemble at the observatory helps to improve the short term stability of the local time with respect to more long term stable caesium clocks. The masers are primarily used as a stable frequency source for VLBI observations of the radio telescopes at the observatory. Due to the construction of two new telescopes (TWIN), one maser of the ensemble was installed in the TWIN operations building and serves as a common clock for both TWIN1 (Wn) and TWIN2 (Ws).

In the future, the maser ensemble is foreseen to provide a common clock for all three telescopes to provide geodetic and local VLBI measurements. Due to the separation of the maser ensemble to different buildings and environments, these comparisons have become necessary.

The results from this comparison will contribute to the project of using a steered hydrogen maser for generating the local representation of UTC at the observatory and the improvement of a local composite clock for the observatory, combining caesium clocks, hydrogen masers, and a cold rubidium clock.

2 Measuring Method

The measurement method we used for the comparison of the masers is called the triangular method. These method allows us to derive the performance of each oscillator on its own [Schlüter (1988)].

The triangular method needs three different oscillators which are compared to each other simultaneously (Figure 1).

In this measurement oscillator A is compared to oscillator B, oscillator B to oscillator C, and oscillator C to oscillator A. The simultaneous measurement is necessary to get a set of data that overlaps in time.

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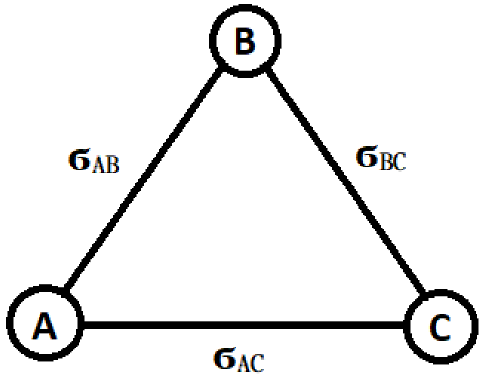

Fig. 1 Schematic draw of a triangular measurement.

Out of the measured data, the Allan variance of an oscillator pair can be calculated. The Allan variance, also known as two-sample variance, is a measure of the frequency stability in oscillators. The Allan variance is defined as [Allan et al. (1966)]:

$$\sigma_y^2(\tau) = \frac{1}{2}\langle(y_{n+1} - y_n)^2\rangle \tag{1}$$

where τ is the observation period and y_n is the nth fractional frequency average over the observation time τ. Just as with standard deviation and variance, the Allan deviation is defined as the square root of the Allan variance:

$$\sigma_y(\tau) = \sqrt{\sigma_y^2(\tau)} \tag{2}$$

With respect to the three oscillators, the measurement leads to the three different Allan deviations σ_{AB}, σ_{BC} and σ_{AC}.

For derivation of the single Allan deviations σ_A, σ_B, and σ_C we can use the law of cosines. If the oscillators are independent then the correlation between the oscillators is zero and we can simplify the law of cosines to the Pythagorean theorem:

$$\sigma_{AB}^2 = \sigma_A^2 + \sigma_B^2 \tag{3}$$

$$\sigma_{AC}^2 = \sigma_A^2 + \sigma_C^2 \tag{4}$$

$$\sigma_{BC}^2 = \sigma_B^2 + \sigma_C^2 \tag{5}$$

The equations solve the following equation, as σ_{AB}, σ_{BC}, and σ_{AC} are known, and, after using the square root, the Allan deviation is extracted from the reference oscillators:

$$\sigma_A = \sqrt{\frac{1}{2}\left(\sigma_{AB}^2 + \sigma_{AC}^2 - \sigma_{BC}^2\right)} \tag{6}$$

The same can be done for σ_B and σ_C. Then the Allan deviation of each single oscillator can be calculated.

3 Measurement Set Up

We were interested in such a measurement because of the fact that our maser clock ensemble is not located in one single building. One maser is separated from the other two by a distance of around 100 m and is in a different building. The maser was relocated; before that, all three masers were at the same building next to each other. In previous measurements we had measured our masers with the same method. Therefore we were interested in whether the relocation had any influence on the maser ensemble's performance.

The measurement took place at the RTW operations building (close to the 20-m telescope Wz), the home of the two masers EFOS18 and EFOS39. The single new maser EFOS60 in the TWIN operations building is connected via a coaxial cable to the other two masers. We were also interested in whether the long cable connection matters with respect to the stability outcome.

Our measurement campaign had a length of 14 days, starting on 2017/12/22 and ending on 2018/01/05. The measurements were performed with a Vremja 314 frequency comparator at a frequency of 100 MHz.

During the measurement, our continuous PPS measurements of the masers were also running. Hence, we can get the long term behavior of the masers and could get a good picture of the drift evolution of our maser ensemble. These PPS measurements are rather simple; every three hours, the PPS signal of a maser is measured against our realization of UTC.

4 Results

The two-week continuous measurement campaign showed the following results: out of the measured frequency differences, the Allan deviations calculated after the described method were calculated. Due to the two-week measurement, a sample time of 10^5 s could

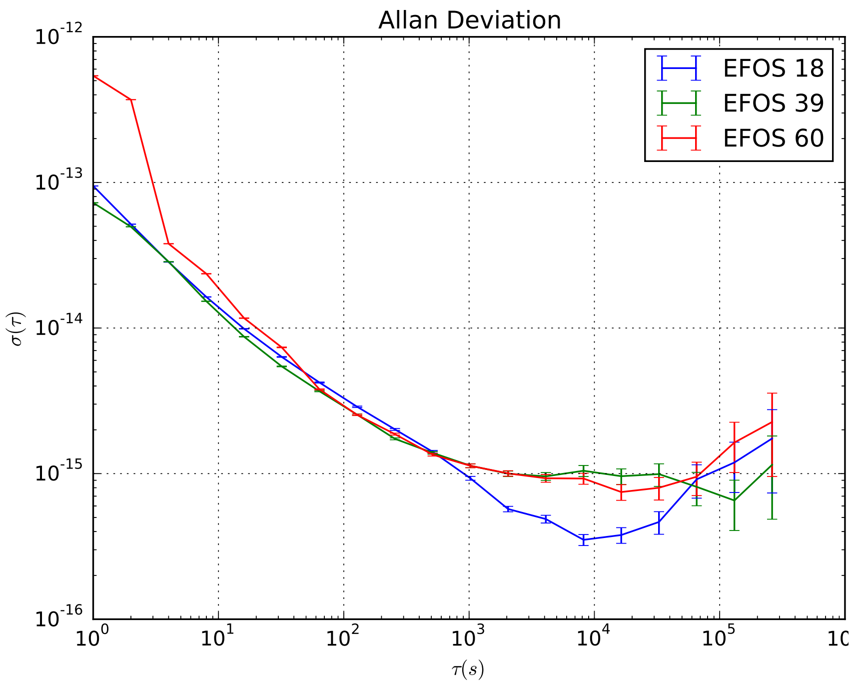

Fig. 2 Allan deviation of the Wettzell maser ensemble EFOS 18 (blue line, middle starting value), EFOS 39 (green line, lowest starting value), and EFOS 60 (red line, highest starting value). The shown graphs are calculated from a 15-day data set, which was measured from 2013/04/03 to 2013/04/18.

be reached for the Allan deviation calculation. For the calculation of the Allan deviation, the Allan tools for python were used [Wallin et al. (2018)].

All three masers show nearly the same expected behavior (Figure 3):

1. Starting with a stability of 10^{-13} at a sampling time of 1 s, we can show that the stability is in the range of the specification of the EFOS masers. The best performance in the 1 s regime is shown by EFOS 39 with a stability of $8 \cdot 10^{-14}$.
2. In the short term regime from 10 s to 1000 s the masers show a $\frac{1}{\sqrt{\tau}}$ behavior. The stability improves from a low value of 10^{-14} at 10 s to a high value of 10^{-16} at 1000 s.
3. After 1000 s of sampling time all masers reach the flicker floor at a stability of $8 \cdot 10^{-16}$. This stability is slightly better than mentioned in the specifications.

In comparison to previous measurements (Figure 2), calculated after the same method, we see no huge differences between the two measurement campaigns. In particular, EFOS 60 did not change in its performance after the relocation.

The PPS measurements (Figure 4) show a constant linear drift for EFOS 18 and EFOS 39. Only EFOS 60 shows some changes in its drift behavior during the two week period, and it is clear there is no linear behavior. Even the sign changes during the campaign.

5 Conclusion

The maser ensemble at the geodetic observatory Wettzell shows the specified behavior of stability (Figure 2), in some cases better than predicted.

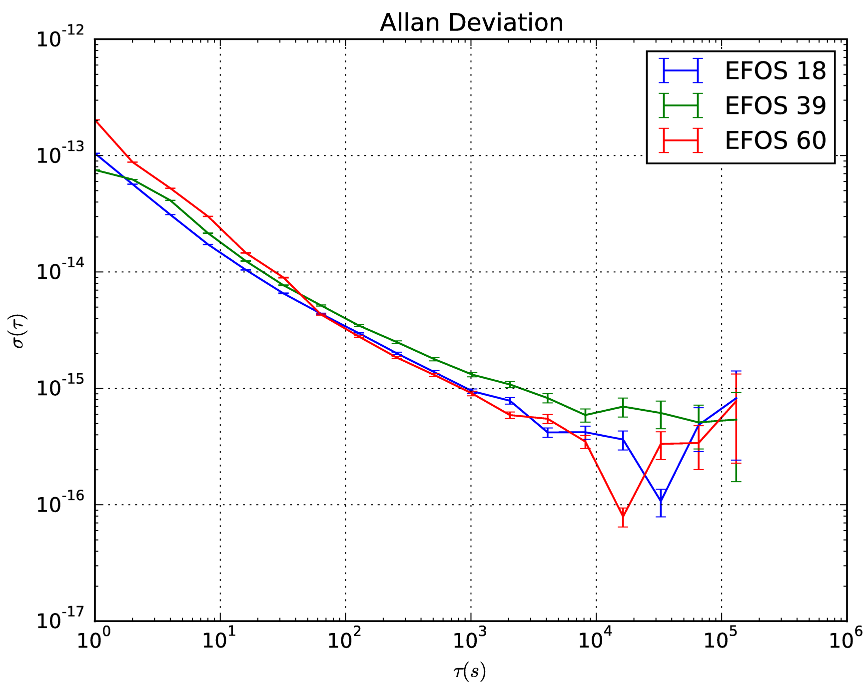

Fig. 3 Allan deviation of the Wettzell maser ensemble EFOS 18 (blue line, middle starting value), EFOS 39 (green line, lowest starting value), and EFOS 60 (red line, highest starting value). The shown graphs are calculated from a 14-day data set which was measured from 2017/12/22 to 2018/01/05.

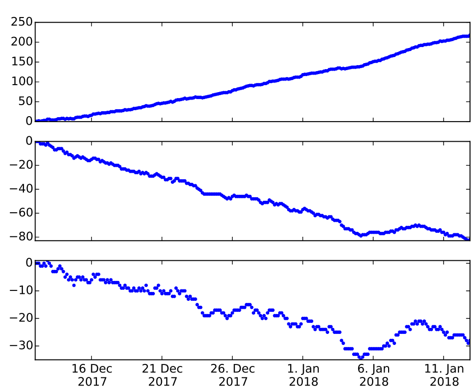

Fig. 4 The drift evolution of Wettzell's maser ensemble: EFOS 18 (upper panel), EFOS 39 (middle panel), and EFOS 60 (lower panel). The evolution of Δt is derived from the measured PPS signals over the time period from 2017/12/13 through 2018/01/12.

The long distance between the maser EFOS 60 and the two others had no effect on the measurement during the campaign. Therefore the distance between the masers should have no influence on measurements such as common clock VLBI measurements with the Wettzell radio telescopes.

The change in the drift behavior of EFOS 60 during the measurement campaign showed no influence on the resulting Allan deviation and had no effect on the short term stability of the maser. This short term stability is required to provide good VLBI measurements. Hence, we assume that a steered maser with small corrections to the drift should have no influence on the short term stability and its usage as a frequency source for our measurements such as VLBI and SLR.

The steered maser could be used as a backbone of the whole time and frequency system of the observatory. In a combination of our optical time and frequency distribution system, a new time measurement system, and the steered maser, we should improve our time and frequency performance for the whole observatory, and the performance of SLR, VLBI, and GNSS measurements should improve as well.

References

[Schlüter (1988)] Schlüter, W., Zeit und Frequenz im Meßverfahren der Geodäsie., Deutsche Geodaetische Kommission Bayer. Akad. Wiss., 337, 1988.

[Allan et al. (1966)] Allan, D. W., Statistics of atomic frequency standards, IEEE Proceedings, 54, Feb. 1966 DOI10.1109/PROC.1966.4634.

[Wallin et al. (2018)] Wallin, A. E. E., Price, D. C., Carson, C. G., and Meynadier, F., allantools: Allan deviation calculation Software, Astrophysics Source Code Library, 2018.